Cognition in the Wild

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4 The Organization of Team Performances

Having presented an account of the performance of the component tasks of the fix cycle in chapter 3, here I will address the ways in which those component tasks can be coordinated to form a larger computational system. In Sea and Anchor Detail, this requires getting the activities of a number of team members into coordination. Thus, in this chapter I consider not only how the tools are used but also how the members of the navigation team use the tools together. The unit of cognitive analysis in this chapter will be the navigation team rather than the individual watchstander.

In anthropology there is scarcely a more important concept than the division of labor. In terms of the energy budget of a human group and the efficiency with which a group exploits its physical environment, social organizational factors often produce group properties that differ considerably from the properties of individuals. For example, Karl Wittfogel (1957, cited in Roberts 1964), writing about the advent of hydraulic farming and Oriental despotism, says:

A large quantity of water can be channeled and kept within bounds only by the use of mass labor; and this mass labor must be coordinated, disciplined, and led. Thus a number of farmers eager to conquer arid lowlands and plains are forced to invoke the organizational devices which—on the basis of premachine technology—offer the one chance of success; they must work in cooperation with their fellows and subordinate themselves to a directing authority.

Thus, a particular kind of social organization permits individuals to combine their efforts in ways that produce results (in this case a technological system called hydraulic farming), that could not be produced by any individual farmer working alone. This kind of effect is ubiquitous in modern life, but it is largely invisible. The skeptical reader may wish to look around right now and see whether there is anything in the current environment that was not either produced or delivered to its present location by the cooperative efforts of individuals working in socially organized groups.

The only thing I can find in my environment that meets this test is a striped pebble that I found at the beach and carried home to decorate my desk. Of course, the very idea of bringing home a pretty pebble to decorate a desk is itself a cultural rather than a personal invention. Every other thing I can see from my chair not only is the product of coordinated group rather than individual activity, but is *necessarily* the product of group rather than individual activity.

All divisions of labor, whether the labor is physical or cognitive in nature, require distributed cognition in order to coordinate the activities of the participants. Even a simple system of two men driving a spike with hammers requires some cognition on the part of each to coordinate his own activities with those of the other. When the labor that is distributed is cognitive labor, the system involves the distribution of two kinds of cognitive labor: the cognition that is the task and the cognition that governs the coordination of the elements of the task. In such a case, the group performing the cognitive task may have cognitive properties that differ from the cognitive properties of any individual.

In view of the importance of social organization and the division of labor as transformers of human capacities, it is something of a surprise that the division of *cognitive* labor has played such a very minor role in cognitive anthropology. There have been few investigations of the many ways in which the cognitive properties of human groups may depend on the social organization of individual cognitive capabilities. Over the years there has been some interest in the way that the knowledge of a society is distributed across its members. Schwartz's (1978) "distributional model of culture" was one of the best worked out of such approaches. In recent years there has been increasing interest in intracultural variability, the question of the distribution of knowledge within a society (Romney, Weller, and Batchelder 1986; Boster 1985, 1990). For the most part, this recent work has addressed the question of the reliability and representativeness of individual anthropological informants and has not been oriented toward the question of the properties of the group that result from one or another distribution of knowledge among its members.

The notion that a culture or a society, as a group, might have some cognitive properties differing from those of the individual members of the culture has been around since the turn of the century, most conspicuously in the writings of the French sociologist Emile Durkheim and his followers and largely in the form of programmatic assertions that it is true. This is an interesting general assertion, but can it be demonstrated that any particular sort of cognitive property could be manifested differently at the individual and group levels? Making a move in that direction, Roberts (1964) suggested that a cultural group can be seen as a kind of widely distributed memory. Such a memory is clearly more robust than the memory of any individual and undoubtedly has a much greater capacity than any individual memory has. Roberts even speculated on how retrieval from the cultural memory might be different from individual memory retrieval and how a variety of social organizational devices might be required for the continued support of memory retrieval functions in increasingly complex cultures. Roberts explored these issues in a comparison of four American Indian tribes, holding that information retrieval (what Roberts called *scanning*) at the tribal level among the Mandan was more efficient than among the Chiricahua because "the small geographical area occupied by the tribe, the concentrated settlement pattern, the frequent visiting, the ceremonial linkages, made even informal mechanisms (of retrieval) more efficient" (ibid.: 448). Roberts also noted that the tribal-level information-retrieval processes of the Cheyenne had properties that were different from those of the Mandan or Chiricahua. He linked the properties to particular features of social organization: "If the membership of a council represents kin and other interest groups in the tribe, each member makes available to the council as a whole the informational resources of the groups he represents.... Councils have usually been viewed as decision-making bodies without proper emphasis on their function as information retrieval units." (ibid.: 449)

In the sentences cited above, Roberts attributes the differences in retrieval efficiency at the group level to the size of the group, the pattern of interactions among individuals, the pattern of interaction through time, and the distribution of knowledge. Thus, it seems important to come to an understanding of the ways in which the cognitive properties of groups may differ from those of individuals. In the comparison of the physical accomplishments of pre- and post-hydraulic agriculture societies it is obvious that the differences in physical accomplishment are due to differences in the social organization of physical labor rather than to differences in the physical strength of the members of the two societies. Similarly, if groups can have cognitive properties that are significantly different from those of the individuals in them, then differences in the cognitive accomplishments of any two groups might depend entirely on differences in the social organization of distributed cognition and not at all on differences in the cognitive properties of individuals in the two groups. This theme is the topic of the next two chapters.

Sea and Anchor Detail

What role does social organization play in the cognition of the navigation team during Sea and Anchor Detail? In chapter 1 we saw that the ship's documents specify a normative division of labor for this task. The specified roles were listed as follows:

3. The Sea and Anchor Piloting Detail will consist of:
   a. The Navigator
   b. The Assistant to the Navigator
   c. Navigation Plotter
   d. Navigation Bearing Recorder/Timer
   e. Starboard Pelorus Operator
   f. Port Pelorus Operator
   g. Restricted Maneuvering Helmsman
   h. Quartermaster of the Watch
   i. Restricted Maneuvering Helmsman in After Steering
   j. Fathometer Operator
   (When sufficient Quartermasters are available, each of the positions except Navigator, will be filled by a Quartermaster.)

The procedures to be followed and the duties of each member of the navigation team are also given in the watch standing manual. In considering these procedures and the division of labor they imply, it will become apparent that the written procedures are not used by the members of the navigation team as structuring resources during the performance of the task, nor do they describe the actual tasks performed. Furthermore, if a system was actually constructed to perform as specified in the procedures as written, it would not work. Still, the normative procedures are a good starting point and provide a stable framework within which the properties of the system can be described. In the following paragraphs, the elements of the task as specified in the Watch Standing Procedures are interspersed with text discussing the roles of the procedural elements in the constitution of the navigation team as a cognitive system.

4. While operating in Restricted Waters, the following procedures will be adhered to:
   a. Fixes will be taken at least every three minutes (Periodicity may be increased by the Navigator)

The default fix interval is 3 minutes because this permits the simplification of certain computations. This interval can be made shorter by the navigator if more resolution is required. The fix interval is a parameter that controls the rate of sampling the environment.

b. A fix will be obtained immediately following each turn

Because of the nature of the position-fixing and position-projecting computations, a ship's course will be made to approximate a series of straight segments punctuated by turns. This is entirely a consequence of the way courses are steered and positions are computed. With a different computational technology (the satellite-based Global Positioning System, for example), it would be possible to have ship's track consist of smooth curves. There are two problems with fixes taken while the ship is turning. The first is that it is difficult to make accurate observations from a turning platform. Even though the true bearing of the landmark may change little while the pelorus operator is aiming at it, if the ship is turning then the relative bearing of the landmark will be changing at whatever the rate of turn is. This may leave the pelorus operator "chasing" the landmark with the telescopic sight of the alidade. The second problem with fixes taken while the ship is turning is that even if they can be made accurately, they are a poor basis for the projection of the ship's position in the future. It is impossible to know the exact shape of the ship's track while the ship is making the turn, so a position fix in a turn does not permit an accurate projection of where the ship will be at the next fix time. For these reasons, fixes are not normally taken in turns. As soon as the ship steadies on a new course, however, it is desirable to take a fix from which future positions on the new course leg can be projected as straight lines.

c. Each set of bearings and/or ranges will be accompanied by a sounding, which will be compared against plotted position

This element of the procedure establishes a cross-check among the representations generated in the fix cycle. The role of comparison of representations in error detection will be discussed in chapter 6.

d. The Fathometer Log will be maintained by the Fathometer operator

The quartermaster of the watch (QMOW) normally keeps all the logs. In Sea and Anchor Detail, however, the fathometer log is kept by the fathometer operator. This is one of many shifts in the distribution of cognitive labor brought about by Sea and Anchor Detail.

> e. The Magnetic Compass Checkbook will be securred on stationing the Sea and Anchor Detail. Checking headings for each course will be entered in the Deck Log by the QMOW
> f. The Ship's Position Log will be securred on stationing the Sea and Anchor Detail, with annotation to that effect

The magnetic compass checkbook is used in Standard Steaming Watch to keep track of the behavior of the magnetic compasses. This and the ship's position log are secured (put away) during Sea and Anchor Detail because the information that would normally go into them is being generated in much more detail and recorded elsewhere (in the bearing log and the deck log).

> g. If sufficient Quartermasters are available, the Assistant to the Navigator will not tie himself down to the plot. He will instead supervise the entire team with emphasis on the plot, the recorder, and the bearing takers.

The Assistant to the Navigator, the Quartermaster Chief, would like to be able to supervise all the activities of the navigation team. When I first went aboard the *Palau*, the team was operating in this configuration. Unfortunately, the quartermasters were not well enough trained to keep up with the workload, and the chief had to step into the role of plotter. It was not even always possible to fill all the positions with quartermasters. During some of my observation periods at sea, sailors of the signalman rating served as pelorus operators and fathometer operators. The effects of personnel availability on this aspect of team composition is one of the differences that was observed between ships. During Colleen Seifert's observations aboard another ship, for example, the Assistant to the Navigator had a completely supervisory role and evaluated the fixes as they were produced. This element of the procedure concerns the distribution of access to information in the navigation team and can be seen as a specification of one aspect of the computational architecture of the navigation team.

> h. Periodically, every third or fourth fix, the information passed from secondary plot in CIC will be plotted on the Primary plot for comparison purposes.

There is a clear tradeoff here between the costs of constructing the redundant plot and the benefits of increased error detection that it provides. In view of the nature of the representations used, the information from Combat Information Center (CIC) cannot be passed to the bridge in the form of plotted positions. Rather, it is passed in a format that requires additional processing by the bridge team. The information could be passed as raw data (bearings and/or ranges of landmarks), as latitude and longitude coordinates, or in terms that locate the ship relative to the precomputed track. The latter format is most frequently observed. "Combat holds us 30 yards right of track, 600 yards to the turn" is a typical CIC status report. Given such a report, the plotter might "eyeball" the position and say, "I'll buy that." This apparently offhand comment represents the outcome of a computation. The coordinates passed by CIC fit the structure that is available to the plotter on the chart. Remember that the distances to the turns are marked in hundreds of yards. Locating a point on the chart that represents a position 30 yards right of the planned track and 600 yards prior to the next turn is therefore relatively easy. Economical encoding of position in relation to the planned track is possible only if both the bridge navigation team and the Combat Information Center have the *same* track plotted on their charts. The report is about the position of the ship, but it assumes shared representations of the framework with respect to which the position is reported.

This redundant processing by the plotter provides another opportunity for the detection of error through the comparison of independently computed representations. The navigation process generates many representations from sources of data that are reasonably independent. The positions plotted in the CIC, for example, are based on radar returns rather than on visual bearings. The comparison of such representations is a very general theme in the practice of navigation. The measures listed here are simply specifications for Sea and Anchor Detail of procedural strategies that are followed in all navigation. In Standard Steaming Watch for example, the following instruction holds:

> h. During prolonged periods in which no nav aids are available (1 hour or more), both the DRAI [Dead Reckoning Analyzer Instrument] and Nav Sat DRs will be recorded in the Ship's Position Log, and plotted as estimated positions for comparison against the hand DR. If unexplainable differences develop, the Assistant to the Navigator will be called immediately.

We see here again the emphasis on the comparison and correlation of representations from different sources. The chart is the "common ground" on which all of these representations can be compared.

> i. The Navigator will act as overall coordinator of the Bridge Party during Sea and Anchor Detail.

This is another element in the organization of the computational architecture of the navigation team. The navigator is given the authority to reconfigure the navigation team as he sees fit.

> j. If the ship goes into a condition of Reduced Visibility during Sea and Anchor Detail, the senior Quartermaster will man the LN-66 Radar on a time sharing basis with the OOD.

The ship never went into a condition of reduced visibility while I was aboard. As reported in chapter 1, the assistant to the navigator claimed that he would not abide by the procedural specification of the relationship between the CIC and the bridge in reduced-visibility situations. It must be remembered that there is a surface-search radar unit on the bridge that can be used for observing radar bearings and ranges of landmarks (the LN-66 mentioned above). The Assistant to the Navigator should attempt to generate his own navigation data using that device. However, the competition for the use of the radar between the navigation team and the officer of the deck is likely to be intense in such a setting. In reduced-visibility situations, it might be impossible to even see past the edge of the flight deck. The officer of the deck will want to adjust the radar to be most effective in detecting and tracking other ships. The quartermaster using the radar will want to adjust it to measure the bearings and ranges of landmarks. These two uses conflict with each other.

The procedures given above describe the procedures and the division of labor mandated for Sea and Anchor Detail. These have a variety of cognitive consequences at the system level, including changes in the organization of the perceptual apparatus of the system to meet anticipated changes in environmental conditions, robust error-detection procedures grounded in the comparisons of multiple representations of the same situation, increase in work capacity provided by distributing cognitive labor across social space, and self-reflection provided by supervisory functions.

The duties of the individual members of the Sea and Anchor Detail team are further specified as follows:

5. The Navigation Plotter will:
   a. Plot each fix.
   b. Plot periodic fixes from CIC
   c. Maintain a constant DR ahead for a minimum of two fix intervals.
   d. Provide the following information to the Navigator/OOD
      (1) Present position with respect to track
      (2) Present SOG (Speed over the ground.)
      (3) Distance to the next turn, and time at present SOG

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(4) Turn Bearing for the next turn
(5) Set and Drift when determined (approximately every third fix)
(6) Nearest shoal water forward of the beam
(7) If anchoring, distance and bearing to the drop point, slow point, stop point, or back point, whichever is next.

The first three duties of the restricted-maneuvering plotter are straightforward. The items of information listed in paragraph d above are not actually reported on every fix, or even on the stated intervals where specified. Rather, they are provided when they are thought to be of use to the OOD. This requires the plotter to know something about the nature of the work being done by the OOD, so that he can anticipate the OOD's information needs and provide the right information at the right time. As noted in chapter 3, the determination of the relation of the ship to the intended track is greatly simplified by the precomputation of the track.

The ship's speed over the ground may be very different from its speed through the water because the water itself may be moving. The speed over the ground is of concern to the officer of the deck, because it is the rate at which the ship is moving relative to land. The motion of the ship over the ground is the vector sum of the motion of the ship through the water and the motion of the water with respect to land. In harbors, tidal effects may produce very strong currents that can augment or diminish the speed of the ship over the ground. (Racing yacht tacticians on San Francisco Bay sometimes joke that the anchor is the fastest piece of equipment on the boat. In truly adverse current conditions, a boat at anchor with zero speed over the ground may be doing better than a boat sailing fast against a current so strong that its speed over the ground is negative or in the wrong direction.) The direction of the movement of the water over the ground is called the *set*, and the speed of the water over the ground is called the *drift*. This is useful information for the officer of the deck because it affects both the speed over the ground and the handling characteristics of the ship.

6. The navigation Recorder/Timer will:
a. Time each fix to three minutes, or the Navigator's instructions
b. Keep the Bearing Record Book in accordance with the instructions posted therein
c. Inform the Pelorus Operators of nav aids to be used
d. Speak out continuous bearings when ordered to do so
e. Obtain soundings from the Fathometer Operator
f. Record data for at least three LOPs

The navigation recorder/timer provides temporal and informational coordination among the other elements of the navigation team. His timing signals and instructions on the navigation aids to be used control the behavior of the pelorus operators. His entries in the bearing record log are the system's first permanent representation of its relationship to a landmark. The structure of the bearing record log in standard form (OpNav Form 3530/2) is a resource for the organization of action. Its columns and rows are preprinted with labels. Entries must be made in ink, and no erasures are permitted: "If an error is made, the recorder must draw a line through the entry that is in error and enter the correct information leaving both entries legible." (Maloney 1985)

7. The Restricted Maneuvering Fathometer Operator will:
   a. Take soundings and send them to the bridge on request.
   b. Record the time and sounding every time a sounding is sent to the bridge.

The fathometer operator makes a redundant recording of the soundings in the sounding log.

8. The Bridge Wing Pelorus Operators shall:
   a. Acquaint themselves with all available information on the nav aids to be utilized prior to the Sea and Anchor Detail
   b. Clothe themselves for comfort.
   c. Checkout the operation of their Alidade as soon as they reach the Bridge, reporting any discrepancy immediately to the Leading Quartermaster.
   d. Maintain sound powered phone communications with the Recorder.
   e. Take and report bearings to the objects ordered by the Recorder and when ordered by the Recorder.

The pelorus operators must acquaint themselves with the navigation aids so that they will be able to find them when directed to shoot bearings to them. Aboard some ships, the aids are given letter identifiers and are referred to over the phones in that way. This lettering scheme is an example of a feature that benefits one part of the organization while putting costs elsewhere (Grudin 1988). On an entry to an unfamiliar harbor, the landmarks may be labeled in alphabetical order from the harbor entrance to the pier. This simplifies the work at the plotting table because it imposes a coherent ordering on the landmarks. It makes the work of the pelorus operators much more difficult, however, because they must master a set of arbitrary names for the landmarks. Some quartermasters have remarked that this can be a real problem going into a foreign port.

Once on duty, the pelorus operators are expected to stay at their posts for the duration of Sea and Anchor Detail. Since the peloruses are located outside the skin of the ship, it is important that pelorus operators dress appropriately from the beginning so that they do

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not become uncomfortable while exposed to the elements. These prescriptions for the pelorus operators cover several aspects of their contribution to the piloting system. They are required to prepare to do the job, avoid an anticipated failure due to discomfort, test sensors with enough time to make repairs, maintain connection to the rest of the system, and operate as instructed.

9. The QMOW shall:
    a. Maintain the deck log
    b. Maintain the Gyro Behavior Log
    c. Maintain a copy of the Pac Fleet Organization Manual
    d. Maintain a copy of the Rules of the Road for immediate reference.

This is a contraction of the normal duties of the QMOW. The deck log and the gyro behavior log are repositories of memories.

Paragraphs 5–9 of the Watch Standing Procedures lay out the allocation of jobs to the members of the team and the interlocking system of functions they perform. Since the work of the team is a computation, we can treat this as a computational system and treat the social organization of the team as a computational architecture.

Social Organization as Computational Architecture

In a paper titled "Natural and Social System Metaphors for Distributed Problem Solving," Chandresekaran (1981) discussed properties of distributed problem-solving systems. Chandresekaran took social systems as a base domain for the metaphorical organization of distributed computer systems. Of course, the computational properties of the computer systems that are built on the social metaphors may also be computational properties of the social systems themselves. Thus, although it is not customary to speak of the computational properties of social institutions, the navigation team in Sea and Anchor Detail can be seen as a computational machine. In this section I explore this metaphor, looking at the ways in which aspects of the behavior of the system can be interpreted in a computational framework. This seems to me a much more solidly grounded application of the computational metaphor to a cognitive system than the application of this metaphor to the workings of an individual mind. See chapters 7 and 9 for further discussion.

When computational tasks are socially distributed, there are two layers of organization to the activity: the computational organization, as defined by the computational dependencies among the various parts of the computation, and the social organization, which structures the interactions among the participants to the computation.

Activity Score

In order to examine the properties of the performance of the navigation team, it is useful to have a representation of the activity that makes clear the relations among the activities of the various members of the team.

Figure 4.1 is an activity score for a typical position fix. The purpose of the activity score is to show the temporal pattern of activity across the representational media that are involved in the fix cycle. Along the left axis of the figure are the names of the media, the sensors at the bottom and the "higher-level" processing media (such as the chart) at the top. Across the bottom is a time scale marked off in 2-second intervals. Each fill pattern in the score denotes the activities that involve the coordination of representations of a single landmark bearing. The first event shown, at the extreme left of the diagram, is the "stand by to mark" signal that brought the bearing recorder and the two pelorus operators into coordination.

As indicated in the Watch Standing Procedures, the pelorus operators should aim their alidades at their landmarks when they receive the "stand by to mark" signal from the recorder. This is indicated in the activity score by the regions that show simultaneous coordination of each pelorus operator with his alidade and an element of the world of landmarks (beginning at time 59). In this case, the starboard pelorus operator had the landmark called Dive Tower and the port pelorus operator had Point Loma. Immediately before giving the "mark" signal, the recorder and the plotter were discussing which landmarks to use on this fix. This caused the recorder to be late giving the "stand by to mark" signal. The interval between the "stand by to mark" and "mark" signals was less than 3 seconds, rather than the usual 10 seconds. The team is on a 2-minute fix interval at this point. This is one of the reasons that the recorder rushed the mark signal. The fix is accompanied by a sounding that is provided by the fathometer operator via the phone circuit just after the "mark" signal. The fathometer operator, who expects to have a 10-second window between the "stand by to mark" and "mark" signals in which to report the depth, began to read the depth while the recorder was giving the "mark" signal. He

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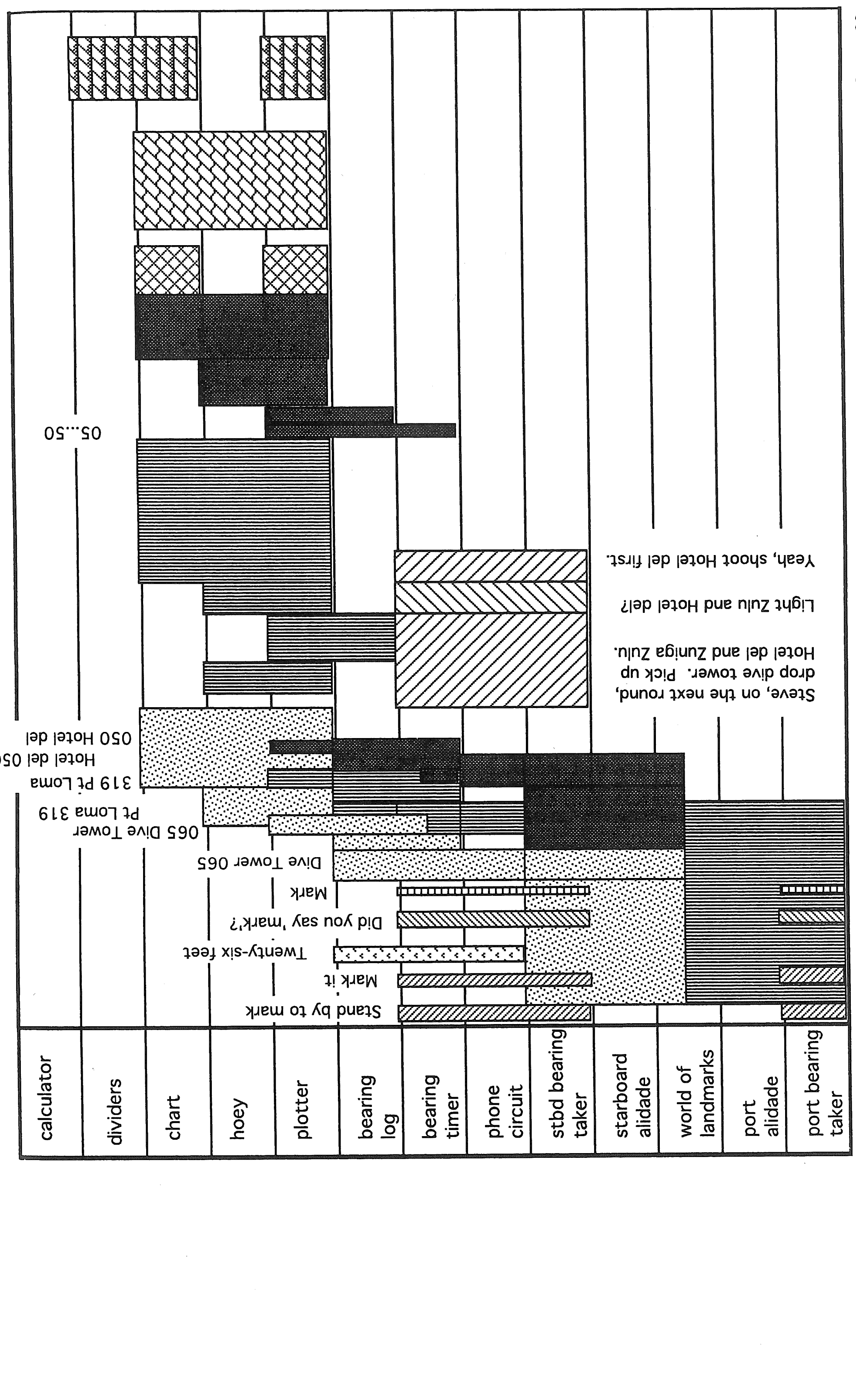

Figure 4.1 An activity score for a fix cycle. The activity score shows temporal relations among coordinated activities of members of the navigation team.

deferred to the recorder and then repeated the depth report immediately after the mark signal.

The "mark" signal also seemed to take the pelorus operators by surprise. They were probably still locating their landmarks and aiming their alidades when it arrived. About $3\frac{1}{2}$ seconds after the "mark" signal, the starboard pelorus operator asked "Did you say 'mark'?" The recorder answered by simply repeating the "mark" signal (at time 06). Any additional explanation offered by the recorder at this point would only have delayed the fix even more. The starboard pelorus operator read the bearing of the Dive Tower and reported it (at time 08).

While recording the bearing in the log, the bearing recorder read the bearing aloud for the plotter to hear (at time 10). Meanwhile, the port pelorus operator aligned Point Loma in the sights of his alidade and reported the bearing of Point Loma just as the bearing recorder was reading the Dive Tower bearing to the plotter (at time 11).

Upon hearing the bearing from the recorder, the plotter said "OK" and aligned the scale of the hoey to reproduce the bearing (at time 11–13). He then aligned the hoey with the chart and plotted the line of position for Dive Tower (time 13–18).

Just after the plotter applied the hoey to the chart to plot the LOP for Dive Tower, the recorder read aloud the bearing to Point Loma. Since the plotter had already aligned and locked the hoey, he was no longer dealing with the bearing to Dive Tower as a number. Hearing the spoken bearing to Point Loma probably interfered little with the task of getting the aligned hoey into coordination with the directional frame of the chart. If the plotter had still been aligning the hoey scale when the new bearing was spoken, we might have expected some destructive interference between the two tasks.

While the bearing recorder was repeating the bearing to Point Loma, the starboard pelorus operator reported the bearing to Hotel del Coronado ("Hotel del"). Again, the overlap between the speaking and listening tasks did not cause destructive interference. The pelorus operator pronounced the name of the new landmark while the recorder was speaking the name of the previous landmark. The numbers did not overlap.

When the plotter had finished plotting the LOP for Dive Tower, he began scaling the hoey for Point Loma. He may have been able to attend at least partially to the spoken report of the bearing while he was placing the hoey on the chart a few seconds earlier. However, after fiddling with the hoey for 2 seconds he looked into the bearing log and read the bearing of Point Loma (time 21–24). He then returned to the scaling task (time 24–26) and then applied the hoey to the chart and plotted the LOP (time 26–35).

Meanwhile, the bearing recorder was instructing the starboard pelorus operator on a change of landmark that the recorder and plotter had decided upon in the seconds leading up to the current fix.

The bearing recorder completed his instructions to the starboard pelorus operator while the plotter was still plotting the Point Loma LOP. When the recorder saw that the plotter had finished plotting Point Loma, he read the bearing of Hotel del aloud from the bearing log (time 35). The plotter had already turned to the log and read the bearing there (time 36) before setting the bearing into the state of the hoey (time 37–40) and plotting the LOP (time 40–44).

After plotting the third LOP, the plotter marked and labeled the fix (time 44–47). He then went on to extend the dead reckoning positions (time 48–60).

This example illustrates a number of interesting properties of the team performance of the fix cycle.

Parallel Activities

Perhaps the most obvious property is that the activities of the members of the team take place in parallel. For example, at time 11 the port pelorus operator was reporting the bearing of Point Loma to the recorder, who was at that moment reporting the bearing of the Dive Tower to the plotter. At the same moment, the starboard bearing taker was aiming his alidade at the Hotel del landmark.

This is a clear example of the simultaneous coordination of many media in a functional system that transcends the boundaries of the individual actors. In chapter 3, identifying the landmark, aiming the alidade, reading the bearing, and reporting and remembering the bearing were each described as processes in which a set of mutually constraining media are placed in coordination by the pelorus operator. In chapter 3 we also saw how recording the bearings involved the construction of a complex functional system by the bearing recorder. Now we see that these two functional systems were assembled into a larger functional system in the coordination of the activities of the two crew members. Here two team members, the pelorus operator and the recorder, worked together on a single problem.

This example also demonstrates simultaneous activity within a single individual. The bearing recorder was reading one bearing and listening to another at the same time. The overlap of activity is such that there is no destructive interference between the two tasks, although if the timing was even a few tenths of a second different there could be. The recorder's words and the port wing bearing taker's words overlap like this:

Recorder:	0 6 5	Dive Tower
Port Wing:		Point Loma 3 1 9.

Bottom-Up and Top-Down Processes

The propagation of the bearings from the alidades to the chart is a "bottom-up" information process. The representation of the relationship of the ship to the world is transformed into symbolic form and moved across a set of media until it arrives at the chart. In an idealization of the fix cycle, information flows bottom-up, from sensors to central representation, in the first part of the cycle; it flows top-down, from the central decision makers to the sensors, in the latter part of the cycle, when the pelorus operators are instructed to shoot particular landmarks. The general trend is apparent in figure 4.1 in the form of the upward slope of activity regions from left to right. The top-down activities in the fix cycle are more diverse. As soon as the bearings had been reported, the recorder instructed the starboard pelorus operator to shift to a new landmark.

The "stand by to mark" and "mark" signals are also top-down messages. This example illustrates some of the potential complexities of the flow of information in the system. Because of a disruption of the recorder's activities, the expected mark signal came at an unexpected time.

Other top-down messages guide the sensors to targets in the world. For example, the recorder instructed the pelorus operator: "Shoot the end part that is away from you." On another occasion, the plotter asked the recorder: "Give me a quick line ahead, then back to the Aero Beacon."

Some top-down messages request information about sensor capability. Before a fix, the recorder asked a pelorus operator "Can you still see Bravo pier?" During a fix, when a pelorus operator failed to report, the recorder asked: "Are you still there? What happened, man?"

Top-down messages also give the sensors feedback on their performance. When the LOPs yielded a tight triangle on the chart, the recorder told the pelorus operators "Excellent fix, guys." When the bearing reports were coming in too slowly, he chided "Let's pick up the marking, man." The top-down signals observed in the operation of the navigation team in Sea and Anchor Detail also included recalibrations of the senses. The plotter instructed the recorder as follows: "The fixes are getting open; tell them to mark their heads." To mark heads means to have the two pelorus operators simultaneously report the true heading of the ship with respect to the gyroscope. Any difference between the reported "heads" is an indication of a failure of the gyro-repeater system. This comment from the plotter is simultaneously a complaint about the quality of the information received, an indication of a hypothesis concerning the source of the degradation of the data (that the repeaters are not aligned), and an instruction to perform a procedure that will provide a test of the hypothesis.

Human Interfaces

The creation of human and organizational interfaces to tasks is ubiquitous. Roy D'Andrade (personal communication) has pointed out that in the academic world we appoint discussion leaders to act as interfaces for the rest of us to some particular reading. The discussion leader in the meeting has a rank, a responsibility, and certain privileges that are bestowed by the rest of the group. Aboard a ship, the quartermaster chief has the authority to make one of his men an interface to a particular task. From a functional perspective, the navigation team is the conning officer's interface to the navigation problem. The team provides mediation of such a complex form that it is barely recognizable as mediation.

DAEMONS

A commonly created sort of interface to a task is what in computer science is called a *daemon*. A daemon is an agent that monitors a world waiting for certain specified conditions. When the trigger conditions exist, the daemon takes a specified action.

Setting a depth threshold detector

During an approach to an antenna-calibration buoy near the shore, Chief Richards assigned Smith to the fathometer with instructions to report when the depth of water under the ship shoaled to less than 20 fathoms. This is an example of the social construction of an information-processing mechanism. In this case, the chief had reconfigured the navigation team to create within it a daemon to detect a particular condition. The reconfiguration involved the construction of a short strand of representational state. Smith was stationed at the fathometer, concentrating on the relationship of the marks indicating the depth of water to the labeled 20-fathom line on the echo-sounder graph paper. His job was to detect a certain analog relationship (depth indication above the 20-fathom line) and transform that to a symbolic signal to the plotter.

Continuous bearings

Continuous bearing reporting is a nice case of setting up a somewhat more complicated information-processing structure that detects a single very specific condition. On the open sea, turns are made at specified times or when the ship is reckoned to have reached a specified position. In restricted waters more precision is required. For this purpose, turn bearings are constructed (see chapter 3).

When the ship is approaching the turn bearing, the plotter will ask the recorder to have the pelorus operator on the appropriate side observe the landmark on which the turn bearing is based and give continuous readings of its bearing. These are not recorded in the bearing record log, but are relayed verbally to the plotter. By aligning the plotting tool with the landmark and the spoken bearings, the plotter can move the represented position of the ship along the course line in a relatively continuous fashion. Since the track is marked in 100-yard increments, it is then easy for the plotter to determine and call out the distance to the next turn.

An excerpt from the transcript of the moments leading up to a turn looks as follows. (The turn bearing is 192° on North Island Tower. The CIC COMM is a phone talker who relays information between the chart table and the plotting table in CIC. See figure 4.2 for the position of the ship during this event.)

Plotter: OK. What course is he on? OK, how about continuous bearings . . .

Recorder: Continuous bearings on North Island Tower.

Plotter: . . . on the Tower.

Recorder: 2 2 9 . . . 2 2 8 . . . 2 2 7 . . . 2 2 6 . . . 2 2 5 . . . 2 2 4 . . .

Plotter: Five hundred yards to the turn. Next course will be 2 5 1.

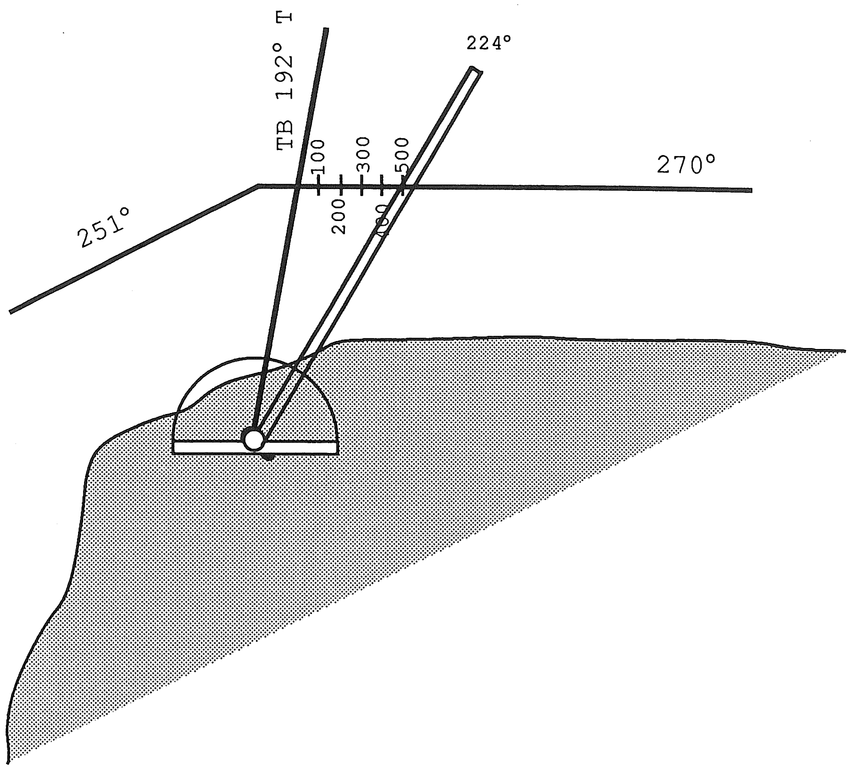

Figure 4.2 Moving the hoey arm in coordination with continuous bearing reports. The turn bearing for this turn is 192° to North Island Tower. The plotter, having aligned the hoey with the chart, holds the base steady and moves the arm of the hoey to each of the bearings as it is reported. This permits him to read the distance to the turn directly off the chart.

CIC Comm: Navigation holds 500 yards to the turn.

OOD: Very well.

Plotter: Ah . . . see if I try 8 knots, 8 and a half maybe.

CIC Comm: Combat holds 420 yards to the turn.

Recorder: 2 2 1 . . . 2 2 0 . . . 2 1 9 . . . 2 1 8 . . . 2 1 7 . . . 2 1 6 . . . 2 1 5 . . . 2 1 4 . . .

Plotter: Three hundred yards to the turn. Next course 2 5 1.

Recorder: 213

CIC Comm: Navigation holds 300 yards.

Recorder: 2 1 2 . . . 2 1 1 . . . 2 1 0 . . . 2 0 9 . . . 2 0 8 . . .

Plotter: Two hundred yards to the turn.

Recorder: 2 0 7 . . . 2 0 6 . . . 2 0 5 . . . 2 0 4 . . . 2 0 3 . . . 2 0 2 . . . 2 0 1

Plotter: One hundred yards to the turn.

CIC Comm: Navigation holds 100 yards to the turn.

Recorder: 2 0 0 . . .

Plotter: One hundred yards to the turn.

Recorder: 1 9 9 . . . 1 9 8 . . . 1 9 7 . . . 1 9 6 . . . 1 9 5 . . . 1 9 4 . . . 1 9 3

Plotter: Recommend coming left 2 5 1.

Recorder: 1 9 2 . . .

OOD: Left 15 degrees rudder. Steer course 2 5 1.

CIC Comm: Left 15 degrees rudder, change course 2 5 1.

Helm: Change course 2 5 1, aye sir. Left 15 degrees. Course 2 5 1.

OOD: Very well.

The recorder also had access to the chart and knew which landmark the bearings would be taken on before the plotter had finished telling him to begin continuous bearings. Every bearing spoken out by the recorder was spoken out just the instant before by the pelorus operator. The trajectory of representational state in this case flows without interruption from the relationship between the ship and the world to the state of the pelorus to the bearing spoken by the pelorus operator to the bearing spoken by the recorder to the state of the hoey on the chart to the advice announced by the plotter for the OOD to begin the turn. In making a turn in Sea and Anchor Detail, the system hooks up four people and a suite of technology into a tightly coupled functional system. It is a temporary structure that brings media and processes into coordination in order to track the ship's relationship to its environment on a finer time scale than in normal operations. This entire functional system is organized around the detection of a single condition: the arrival of the ship at the turn point.

BUFFERS

The bearing recorder and bearing record log are information buffers. They enable the pelorus operators, whose job is to make the observations as nearly simultaneously as is possible, and the plotter, whose job is to get the lines of position onto the chart, to operate asynchronously. There is a great deal of variation in the pace of the work done by the members of the navigation team. The buffering activity of the bearing recorder introduces slack into the system so that the temporal constraints of the pelorus operators do not interfere with the temporal constraints of the plotter. The bearing record log is also a special kind of filter that passes the bearings without passing the temporal characteristics of their production. In this way, it inhibits the propagation of some kinds of representational state. Without this buffering, the reports of the pelorus operators might interfere with the plotting activity of the plotter, or data might be lost because both sender and recipient were unable to attend to a message at the same time.

The bridge team is connected to other parts of the ship by sound-powered phone circuits like the one used by the pelorus operators and the bearing recorder. These lines provide the bridge team with communication links to the foc'sle, to after-steering, to the combat information center, to the signal bridge (where lookouts are posted), and to other locations on the ship. There is a person called a *phone talker* posted at each end of each of these phone lines. The numerous phone talkers around the ship are also information buffers. Each pair of them permits communication to take place when the sender and the receiver are not overloaded. For example, rather than simply blurt out whatever message has arrived, a bridge phone talker can wait for a pause in the OOD's work to pass a message to him. The phone talker can hold the message until an opportunity to insert it into the activity on the bridge has arrived. Someone sending a message to the bridge from another part of the ship cannot know when would be an appropriate moment to interject the message. The phone talker is a sophisticated buffer who uses his knowledge of conversational turn taking to decide when to forward a message.

Buffering contributes to what Perrow (1984) has called "loose coupling" of the system. The buffering prevents the uncontrolled propagation of effects from one part of the system to another. Buffering provides protection against destructive interference between processes running in parallel.

Communication and Memory

In any implementation of the fix cycle, representational state needs to propagate physically from the pelorus to the bearing record log and then to the chart. In Standard Steaming Watch, the states are propagated from the pelorus to the memory of the watchstander and then transported from the pelorus to the bearing record log. In Sea and Anchor Detail, the state is also propagated from the pelorus to the mind of the pelorus operator, but it is then propagated by way of communications technology to the mind of the bearing recorder. It is then propagated to the bearing record log. Thus, the work that is done by individual memory in the solo condition is replaced in the group condition by interpersonal communication. Perhaps this should come as no surprise. If we think of individual memory as communication with the self over time (Lantz and Stefflre 1964), then the replacement of intrapersonal communication by interpersonal communication is an expected consequence of the move from individual to team performance of a task.

For example, the quartermaster in Standard Steaming Watch will have to remember which landmarks have been chosen while moving from the chart table to the peloruses on the wings. More challenging, the quartermaster will have to remember or record the observations as they are made, so that they can be recalled and recorded in the bearing log. The chart and the bearing log are located in the pilothouse, while the peloruses are located on the wings. Between the time when the first observation is made and the time when the bearings are recorded in the bearing record log, the quartermaster will have to make two other observations and then return to the chart table. Some watchstanders rely on spoken rehearsals of the bearings to remember them. In this case only the numbers are usually rehearsed, not the numbers and the names. The assignment of names to the numbers can be made at the chart, and the position of the lines on the chart can help the quartermaster remember which landmark has the bearing being plotted. The problems with this are that the subsequent bearings may interfere with the earlier ones; that the talk in the pilothouse itself often is filled with unrelated numbers, so it too may interfere; and that if the chart is being used to disambiguate the assignment of landmarks to remembered bearing numbers, the power of error checking at the chart is sharply diminished. Other quartermasters jot the bearings down on a sheet of paper or on one hand as each is observed. If the landmarks are off to the port side of the ship and the weather is cold, the quartermaster may have to walk aft to gain access to the port pelorus via the passageway at the back of the island because the captain will not permit the door behind his chair to be opened. This means that the bearing will have to be remembered longer, which introduces additional cognitive requirements. This is an example of the way that the cognitive requirements of real-world task performance may be driven by unexpected factors.

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Task Allocation and Equipment Layout

The arrangement of equipment in a workplace might seem to be a topic for traditional, noncognitive ergonomics. However, it has an interpretation in terms of the construction of systems of socially distributed cognition. The interaction of the properties of the senses with the physical layout of the task environment defines possibilities for the distribution of access to information. For example, the location of the fathometer in the charthouse, away from the bridge, makes a distribution of labor necessary in order to meet the time requirements of Sea and Anchor Detail. It is simply not possible for a single watchstander to make the required observations in the allotted time, given the physical locations of the equipment. In fact, the computational consequences of the locations of equipment may interact in unexpected ways with other aspects of the ship's operation. In Standard Steaming Watch a single quartermaster may be responsible for all navigation activities. While making the bearing observations for the fix, the QMOW must go out on the wings. The starboard pelorus is within 10 feet of the chart table, and it is easily accessed through a nearby door. The port pelorus is about 30 feet from the chart table, just outside a door on the port side of the bridge. On this particular ship, however, if the captain is on the bridge, taking a bearing with the port pelorus can involve an absence from the chart table of up to a minute. The reason is that, as was mentioned above, the captain likes to keep the door immediately behind his chair closed while he is on the bridge. In order to get to the port pelorus, the QM must go aft to a doorway at the back of the port wing and walk forward on the wing to reach the pelorus. Upon returning to the pilothouse, the QM should then go to the helm and leehelm stations to see if any changes in course or speed have been ordered in his absence.

Chief Richards says it would be nice to have instrument repeaters at the chart table. A speed log repeater would be especially useful. In Sea and Anchor Detail, the QMOW should be able to keep track of speed and heading changes by attending to the commands issued by the conning officer to the helmsman and the leehelmsman. In practice, however, it is not always possible to do this. Speed and heading are also available to the QMOW on instruments, but the instruments are not conveniently located. Their placement requires the QMOW to leave the vicinity of the chart table to acquire this information. The master gyrocompass is located in the steering binacle, and the speed display is forward on the port side of the bridge, in front of the captain's chair. These facts have nontrivial consequences for the information-processing properties of the navigation team.

Sequential Control of Action

Russian legend has it that Prince Potemkin once organized a band in which each musician had a horn, but each horn could only sound one note. To play a piece, "the players had to be extremely skillful in order to preserve the synchronic performance of all the instruments and weave their own note into the melody at the right time" (Kann 1978: 52). Playing in Potemkin's horn band was apparently an enormously difficult coordination task. Sequential control was achieved by having every musician know the plan of the entire piece and also know the place of every instance of his own note within the piece.

A procedure is *sequentially unconstrained* if the execution of any enabled operation will never disable any other enabled but as yet unexecuted operation. A task that has no sequential constraints can be accomplished by a "swarm of ants" strategy. In such a scheme, there is no communication between the active agents other than their effects on a shared environment. Each agent simply mills about taking actions only when he encounters situations on which he can act.

A procedure is *sequentially constrained* if the execution of any enabled operation will disable any other enabled but as yet unexecuted operation. Where there are sequential constraints, it is necessary to have some control over the sequence of actions.

The performance of a sequentially constrained procedure may require planning or backtracking. For example, getting dressed is sequentially constrained because at the moment in which one has neither shoes nor socks on, putting on shoes disables the operation of putting on socks. The sequence of operations for orthodox dressing contains a sequential constraint on the donning of socks and shoes.

Whether a task is sequentially constrained may depend on the representation of the task as well as on the formal properties of the task. Zhang (1992) has recently shown that it is possible to change the sequential constraints of isomorphs of the Tower of Hanoi problem by embodying some of the sequence-constraining "rules" in the physical instantiation of the problem. For example, in one

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version of the puzzle, placing a smaller disk on a larger disk is a violation of a sequence-constraining rule. In Zhang's coffee cup isomorph, this same move would be executed by placing a small coffee cup in a larger one—an act that causes coffee to spill. These are ways to build the sequential constraints into the behavior of the game tokens and thereby reduce the requirement for memory of sequence-constraining rules in support of planning and backtracking.

One general technique for turning sequentially constrained tasks into sequentially unconstrained tasks is to manipulate the enablement conditions of various operations. A simple rule is "suppress the enablement of any operation that could disable another already enabled operation." This can be done through interlocks. In many automobiles, for example, the starter motor will not turn unless the transmission is in park or neutral. This is the mechanical enforcement of a sequential constraint on the engine-starting procedure.

THE NAVIGATION TEAM AS A PRODUCTION SYSTEM

Sequentially unconstrained procedures are easily distributed or can be solved by very loosely interconnected systems. Tasks that have sequential constraints require some coordination among the actions to be taken. There are many ways to achieve this coordination. Specifying the overall pattern of behavior in a script, a score, or an overall plan is an obvious solution to the sequencing problem. Since there are many sequential constraints among the actions of the fix cycle, one might assume that the fix cycle unfolds according to a stored plan or description of the sequence of actions involved.

In fact, it is possible for the team to organize its behavior in an appropriate sequence without there being a global script or plan anywhere in the system. Each crew member only needs to know what to do when certain conditions are produced in the environment. An examination of the descriptions of the duties of the members of the navigation team shows that many of the specified duties are given in the form "Do X when Y." Here are some examples from the procedures:

a. Take soundings and send them to the bridge on request.
b. Record the time and sounding every time a sounding is sent to the bridge.
e. Take and report bearings to the objects ordered by the Recorder and when ordered by the Recorder.

These and other instructions suggest that the navigation team could be modeled by a set of agents, each of whom can perceive the environment and can act on the environment when certain triggering conditions appear there. An interlocking set of partial procedures can produce the overall observed pattern without there being a representation of that overall pattern anywhere in the system.

Each participant knows how to coordinate his activities with the technologies and persons he interacts with. The pelorus operators know to negotiate the order of report with each other and to take and report bearings when given the "mark" signal. The recorder knows to say "Stand by to mark" before the mark, then to say "Mark," and then to attend to and record the bearings. The plotter knows to plot the recorded bearings to get a position, and then to project the dead-reckoning positions and choose new landmarks. The plotter's duties may cover a longer procedural stretch than those of any other member of the group, but even they do not come close to completing the cycle. The whole cycle is something that emerges from the interactions of the individuals with one another and with the tools of the space. The structure of the activities of the group is determined by a set of local computations rather than by the implementation of a global plan. In the distributed situation, a set of concurrent socio-computational dependencies is set up. These dependencies shape the pattern of behavior of the group. The existence of the plotter waiting for bearings is how the system remembers what to do with the recorded bearings. These concurrent dependencies are not present in the solo performance case.

When the nature of the problem is seen as coordination among persons and devices, much of the organization of behavior is removed from the performer and is given over to the structure of the object or system with which one is coordinating. This is what it means to coordinate: to set oneself up in such a way that constraints on one's behavior are given by some other system. This is easy to see in the use of the recorder's wristwatch. Perhaps through some complicated toe tapping or counting the recorder could provide a regular meter for the performance of the rounds of fixes and dead-reckoning projections, but that is unlikely. The only way humans have found to get such tasks done well is to introduce machines that can provide a temporal meter and then coordinate the behavior of the system with that meter. The system's coordination with the meter of the watch is provided by the recorder's coordinating with the watch and the others' coordinating with the re-

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corder. The recorder's coordinating with the watch requires him to maintain (1) vigilance to the watch and (2) a test of when it is time to take another round. For the second of these, he must have (1) a procedure for determining (or a memory of) when the next round should fall and (2) a way of determining when that time has been reached. Both parts of this task require some cognition, to be sure, but no sophisticated reasoning.

It should be noted, however, that the members of the team may engage in considerably more cognitive activity than the minimum required. The various actors may have ideas about what a particular task requires, and they may anticipate particular sorts of failures on the basis of these ideas. In the case of the recorder's maintaining coordination with the watch, lack of vigilance due to the appropriation of attention by other tasks may cause the recorder to miss a mark. The plotter, who shares the physical environment of the recorder, apparently sometimes participates in that task redundantly and has been observed to comment "Isn't it about time for a round?"

The coordination problem is more difficult for the quartermaster standing watch alone in the Standard Steaming Watch configuration. In that case, the task performer must not only provide coordination with each of the devices, but must coordinate those activities with other activities. In Sea and Anchor Detail, this latter sort of higher-level coordination is accomplished via the social coordination of the distributed situation. It is still ultimately provided by the human participants, but the cognitive load is not only distributed; it is also lessened by distribution. Here is how: Consider the relation between the pelorus operator and the recorder. The recorder coordinates his activities with the behavior of his wristwatch. That is to say, he has delegated some aspect of the control of his own behavior to this external device. Now, the pelorus operator coordinates his activity with the (timing) behavior of the recorder. He waits for the "mark" signal to read his bearing. He has delegated some aspect of the control of his own behavior to the recorder. He has also delegated some other aspects of his behavior to the device with which he interacts. His behavior is nicely and comfortably constrained by the two coordination activities. He gets the "mark" signal and invokes the coordination with the alidade—which, in its relation to the world, is coordinating him (and, through him, the whole system) with a particular aspect of the setting of the ship in the surrounding world. He reads the bearing. When he does so, the recorder coordinates his (recording) behavior with the pelorus operator. His other activities are on hold while he attends to and (perhaps simultaneously) records the bearing.

The problems of coordination in the solo performance concern the control of the change in roles and the meta-coordination required to move through the sequence of steps required. It is in the consideration of solo performances that the apparent importance of executive function emerges. This is to be expected because, from the point of view of the individual, the task in the solo performance is sequentially constrained in a way that the modular tasks faced by the individual team members in the distributed performance are not. There are certainly still sequential constraints in the distributed form, but each individual is responsible for satisfying fewer of these constraints than in Standard Steaming Watch. In the place of an executive we find a continual collision of interest and negotiation of coordination status.

The quartermasters align themselves as a coordinating structure that passes information from one transforming device to another. The people are the glue that sticks the hardware of the system together. What is the relationship between the position of the ship in the world and the location of the fix on the chart? The formal relationship is one of spatial correspondence. The causal relationship is a tissue of human relationships in which individual watchstanders consent to have their behavior constrained by others, who are themselves constrained by the meaningful states of representational technologies. The sequential constraints of the procedure, which are in part determined by the representation of the problem, constrain the universe of social arrangements in which the procedure can be performed. That is, they specify a coordination task that must be solved by the social organization of work.

SOCIAL STRUCTURE AND GOAL STRUCTURE

The distribution of labor in Sea and Anchor Detail creates a distribution of attention to goals such that the system is unlikely to halt before completing a task. Imagine a problem described by the goal tree shown in figure 4.3a. Individuals engaged in problems with deep goal trees sometimes lose sight of higher-level goals and halt after satisfying a lower-level goal. This is the sort of problem faced by the solo watchstander in Standard Steaming Watch: Having shot a bearing, what should I do next? Now, suppose that rather than a single watchstander we have a team, and we give each

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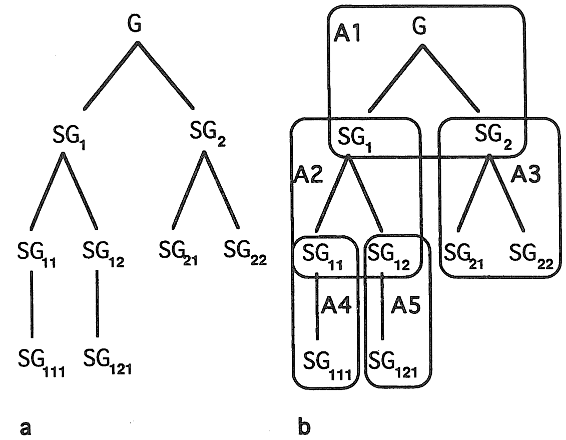

Figure 4.3 Goal hierarchy and distribution of responsibility for goal satisfaction. Responsibility for the satisfaction of the goals shown in panel a can be allocated to agents (the enclosed shapes in panel b) in such a way that social dependencies provide control structure.

member of the team responsibility for a main goal and for the subgoals required to achieve the main goal. The areas of responsibility of the members of the team are superimposed on the goal tree in figure 4.3b. Let the social contract between the agents be such that a subordinate can halt only when his superior determines that the responsibilities of the subordinate have been met. Agent A2, for example, can halt only when agent A1 judges subgoal SG_1 to be satisfied. Each agent is responsible only for a shallow section of the goal hierarchy, so goal stack depth is not a problem for individual processors. Such a setup results in computational control through a network of social relationships. When a problem has a deeply nested goal structure, a social hierarchy can provide a mechanism for distributing the attention to various parts of the goal structure.

Social structure and problem representation both interact with goal structure in the implementations of solutions to the problem of sequential control of action. These things constrain the computational properties of systems of socially distributed cognition and cannot be excluded from an understanding of human cognition as it is manifested in such systems.

The fit between the computational dependencies and the social organization is an important property of the system. We might imagine a situation in which those of higher rank provide input to a lower-ranking individual, who integrates the information and makes decisions. That would be a very strange relationship between the social organization and the computational dependencies. Gathering and providing information for the support of a decision are low-status jobs. Integrating information and making decisions are high-status jobs. There are, of course, exceptions, and some such relationships are more workable than others. In general, however, the goals are in the hands of higher status individuals—those who control the goals are, by cultural definition, of higher status.

Beam Bearings in Sea and Anchor Detail

The members of the navigation team normally take for granted the accomplishment of sequential ordering of their own actions in coordination with one another. The fact that the sequential ordering of action is no simple accomplishment, especially when it is not built into the social or material structures of the task, is highlighted in the case of beam bearings. The *beam* of the ship is those directions that are perpendicular to the keel of the ship. Thus, the bearings of landmarks that are off to either side of the ship, rather than ahead or astern, are called *beam bearings.* The navigation team must both decide which landmarks to observe and determine an order in which to observe them. To produce a high-quality fix, they must make their observations of the landmarks as nearly simultaneously as is possible. The undesirable effects of delays between the observations can be minimized by shooting first the landmarks with which the angular relationship (bearing) is changing most quickly and shooting last the landmarks whose bearings are changing least rapidly.

Why Some Bearings Change More Rapidly Than Others

The rate of change of a bearing depends two things: (1) the component $\mathbf{v}$ of the relative velocity vector that is perpendicular to the line joining the objects and (2) the distance between them, $\mathbf{d}$. Thus, $dB/dt = \mathbf{v}/\mathbf{d}$. For objects of equal distance from the ship, the bearings of those objects off to the side of the ship, rather than those that are ahead and astern, will be changing most rapidly, because nearly all of the relative velocity of the object with respect to the ship will be perpendicular to the line joining the object and the ship. This is not the only consideration, however, since for any given relative bearing objects that are nearer will change in bearing faster than objects that are farther away. Distance and relative bearing affect the rate of change of bearings, and the total time between observations affects the magnitude of the errors in the observations. The quartermasters must therefore shoot the bearings quickly and in the correct order.

Example of Effects of Beam Bearings

A ship with a speed over the ground of 10 knots will cover 1000 yards in 3 minutes. Suppose a bearing 1000 yards out on the beam of the ship is taken 10 seconds late. What effect will this have on the plotted position? The ship will have moved 55 yards in those 10 seconds, so the line of position defined by that landmark's bearing will be 55 yards further down track than it should have been (figure 4.4). All of the forward motion of the ship is captured in the observation of a beam bearing; for this reason beam bearings are also called *speed lines*. Now consider a bearing ahead or astern of the ship. The ship moves the same 55 yards in those 10 seconds, but the direction from the ship to landmarks ahead and astern

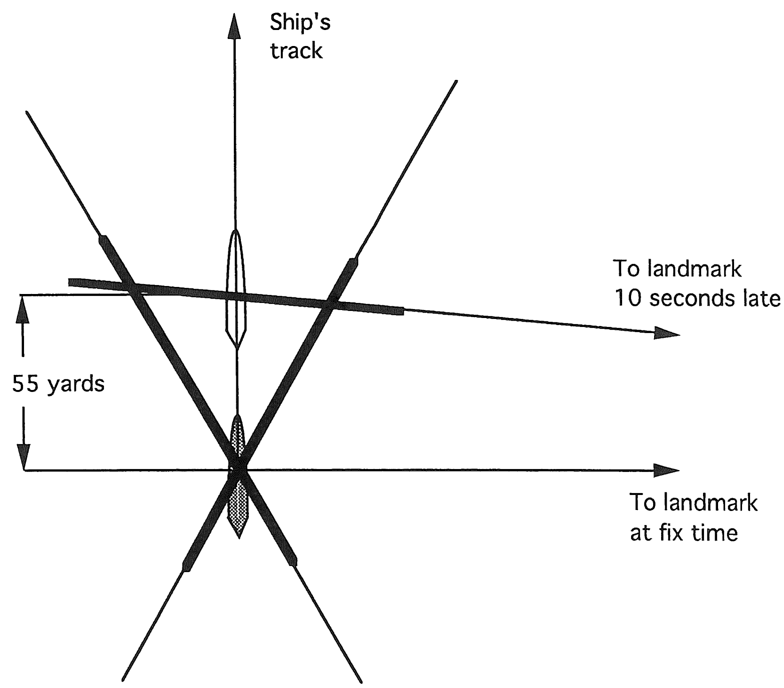

Figure 4.4 The effects of a late beam bearing. Heavy lines indicate the portions of the bearing lines that are actually drawn on the chart to plot the fix. The darkened shape depicts the location of the ship at fix time. The light shape depicts the location of the ship 10 seconds after the fix time.

changes little. The component of relative motion between the objects that is perpendicular to the line connecting the objects is small, so the rate of change of the bearing is small, and the magnitude of any error caused by delayed observations will also be small.

The Rule of Thumb

The requirement of this geometry is captured in the rule "Shoot the beam bearings first." This rule ignores the distance of the landmark from the ship. In principle distance could be an important factor, but in practice it is not. This procedure is most critical when the ship is in a channel, and in that case bearings on the beam tend not to differ greatly in distance from the ship. Furthermore, the measurements and calculations required to assess the effects of differing distances of objects could be a more serious disruption of the fix procedure than the errors caused by ignoring those effects. Thus, to shoot the beam bearings first is a good rule of thumb to use in sequencing the observations.

Configuring the Team

The application of the "shoot the beam bearing first" rule to the Standard Steaming Watch situation is straightforward. The bearings must be observed sequentially, and the beamiest bearing should be observed first. In Sea and Anchor Detail, two pelorus operators work in parallel while shooting the three bearings. One of the pelorus operators will have two bearings to shoot; the other will have just one bearing. How should the pelorus operators sequence their actions in order to produce the best fix?

Finding a procedure for performing this sequentially constrained task turns out to be a nontrivial problem for the crew. It must be kept in mind that the port pelorus operator may not be able to see the landmarks assigned to the starboard pelorus operator and vice versa. Any bearing on the beam of one side of the ship will not be visible to the pelorus operator on the opposite side, so neither pelorus operator can see enough to decide who has the beamiest bearing. The directional relationship between the bearings is easier to imagine at the chart table, but determining the shooting sequence there would impose an additional burden on an already busy bearing recorder. Before we examine what the crew actually does with this problem, it may be useful to indicate the form of the

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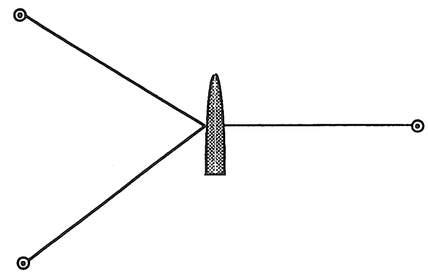
correct solution. The sequencing of observations could have adverse consequences if the order in which the elements of the procedure were executed delayed the observation of a landmark. The bearing recorder is a limiting resource in this procedure because he can attend to only one bearing report at a time. Imagine that the starboard pelorus operator has one landmark to shoot, and that it is on the beam. The port pelorus operator has the other two landmarks, but they are not so beamy as the one to starboard. Figure 4.5 depicts this situation.

If the pelorus operator with the beamiest bearing goes first, and going first is understood to mean both shooting and reporting, then the sequence of actions shown in figure 4.5a will result. (This figure is intended only to show relative times of completion.) The solution shown in figure 4.5.a mimics the structure of the performance when it is done by a single watchstander. It fails to take advantage of the parallelism of activity that is possible with two pelorus operators.

Both of the pelorus operators could observe a bearing immediately upon hearing the "mark" signal. If each pelorus operator observes the "beamiest" of the assigned bearings immediately, and they still report the beam bearing first, the sequence shown in figure 4.5b will result. The port pelorus operator will have to wait while the starboard pelorus operator reports the bearing of the landmark on the beam because the bearing recorder can only attend to one report at a time. This is an improvement over the previous solution because it packs the same number of actions into a smaller period of time, thus reducing the magnitude of the errors in position caused by delays in making the observations. In particular, the first bearing observed by the port pelorus operator is shot at the mark signal, rather than after the starboard pelorus operator has shot and reported a bearing, and the second bearing observed by the port pelorus operator now comes one action cycle earlier. This implementation takes advantage of some of the parallelism of activity that is possible with two pelorus operators.

A further gain can be achieved by realizing that the observation of the bearing and the report of the bearing can be procedurally separated from one another. The computational constraint is on the *sequence and times of the observations*. The beam bearings must be shot before less beamy bearings, and the three observations must be made as near in time to the mark signal as is possible. *There is no similar constraint on the reporting of the observations*. As far as the



Mark

Port	Wait	Wait	Shoot	Report	Shoot	Report
Stbd	Shoot	Report				

a

Mark

Port	Shoot	Wait	Report	Shoot	Report
Stbd	Shoot	Report			

b

Mark

Port	Shoot	Report	Shoot	Report
Stbd	Shoot	Wait	Report	

c

Figure 4.5 Coordinating the actions of the pelorus operators. With two landmarks to port and one to starboard, the pelorus operators can organize their actions in several possible sequences. (a) No overlap of activity; shoot and report actions linked; beamiest bearing reported first. (b) Overlapping observations (beam bearing shot at mark); beamiest bearing reported first. (c) Overlapping observations (beam bearing shot at mark); pelorus operator with two landmarks reports first.

Shoot	Report

Report

to port and one to starboard,
sequences. (a) No overlap of
rst. (b) Overlapping observa-
(c) Overlapping observations
orts first.

quality of the fix goes, as long as the three bearings are accurate, they may be reported in any order—beam first, beam second, or beam last. In order to take full advantage of the parallelism of action that is possible in the team configuration, two rules are required: (1) Each pelorus operator should shoot the beamiest of the landmarks assigned to him immediately at the mark signal, and (2) the pelorus operator who has two bearings to shoot and report should report first. The application of these two rules results in the pattern shown in figure 4.5c.

Instructions Concerning Beam Bearings

When explained with diagrams like those shown in figure 4.5, the appropriate patterns of activity are fairly obvious. When the members of the navigation team attempt to organize their efforts in the performance of the task, however, the application to the group condition of the "rule of thumb" that serves so well in the solo task performance case is problematic at best. All of the members of the team seem eventually to "know" and understand the rule, but their attempts to use the rule to coordinate their actions in time repeatedly fail. To see why, consider the instructions that are passed among the members of the team concerning the need to take beam bearings first. In the simplest case, the sequencing instruction may come from the people working at the chart table.

EXAMPLE 1

The landmarks are Hotel del, Dive Tower, and Point Loma. The ship is outbound from the harbor, west of the 1SD channel marker. The ship's course is 270°, so 360° and 180° are the beam bearings. The starboard pelorus operator's name happens to be Mark. Here is the beginning of the round:

Recorder: Stand by to mark, Point Loma, Hotel del, and Dive Tower.

Plotter: Tell him to take Point Loma first. It's on his beam.

Recorder: Take Point Loma first, Mark. Beam bearing first, mark it.

SW: Point Loma 3 5 9.

In this example, an invocation of the rule is embedded in the instructions from the bearing recorder to the pelorus operator concerning the order in which the observations should made. The example is unproblematic, but there is an opportunity here for the

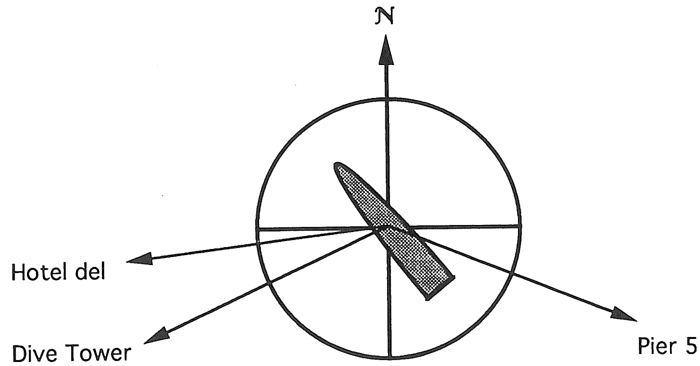


Figure 4.6 The situation of example 2.

pelorus operator to see that Point Loma is an example of a beam bearing and perhaps add to his knowledge of the meaning of the expression. This is thus also an example of language socialization.

EXAMPLE 2

Example 2 is a case in which the recorder chose two landmarks near the beam on the same side of the ship. As a consequence, the lines of position did not converge on a tight fix triangle. The plotter tried to explain the spread of the lines to the recorder. Ship's course: 324°. Beam bearings: 054 and 234. Landmarks: Pier 5 122°, Dive Tower 244°, Hotel del 267°. (See figure 4.6.)

Plotter: See, the reason is ... you get the spread, ah, is that these (Hotel del and Dive Tower) are both close to the beam.

Recorder: Yeah.

Plotter: Right. They are both close to the beam. They're gonna sp ... I mean, unless he can get 'em really, really fast, he's gonna split it even at 10 knots, you know. Ten knots, he is progressing along in between the time he reads those.

Recorder: Yeah.

Plotter: 'Cause they're both so, both so close to the beam.

Recorder: Yeah.

Plotter: That's the reason.

There are two potential problems with what the recorder has done. The plotter explains one of them at length. Since both bearings for the port pelorus operator are near the beam, no matter which one the pelorus operator shoots first, the other will change while he is shooting the first. The second problem is that two bearings within

Pier 5

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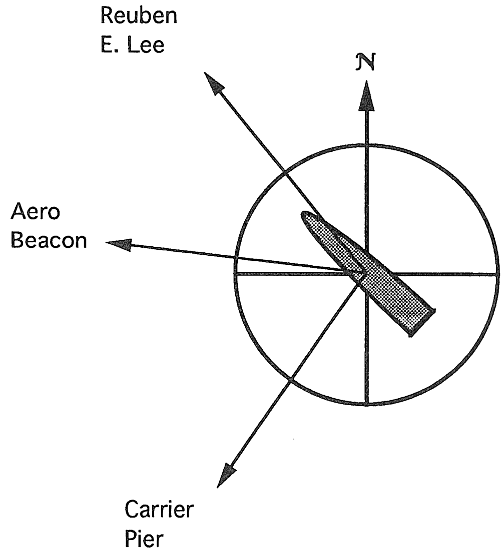

Figure 4.7 The situation of example 3.

30° of each other intersect at a shallow angle, so small errors in the observation move the point of intersection a long ways.

EXAMPLE 3

A beam bearing (to the carrier pier) was the last bearing observed. The plotter and the recorder have discussed the effects of shooting beam bearings last, and the recorder tells the pelorus operators to remember to shoot the beam bearing first. Course: 309°. Beam bearings: 039 and 219. Landmarks: Reuben E. Lee 328°, Aero Beacon 281°, Carrier Pier 210°. (See figure 4.7.)

Recorder (to plotter): That was a late bearing.

Plotter: Yeah, see, he's gotta remember that. These late bearings on beam are doing, is why you get these big open fixes. Your beam bearing's gotta shoot first. Tell those guys to watch what the hell they are doing.

Recorder: That's what I've been tellin' 'em.

Plotter: Yeah, but tell him, OK, over there he's got to go to the beam one first.

Recorder: OK.

Plotter: Because that is the one that is changing on him real fast.

Recorder (to pelorus operators): OK guys. Remember to shoot the beam bearings first.

Notice that much less is communicated to the pelorus operators in the recorder's last turn than what passes between the plotter and the recorder. The plotter and the recorder share the chart as well, and it is a rich communicative resource. When the plotter refers to "these big open fixes" he is pointing to the fix triangles on the chart. The pelorus operators are separated from this scene by the phone circuit. The instruction to them contains only an admonition to shoot beam bearings first.

The next example raises the possibility that the pelorus operators do not know how to make sense of what they are being told, and there is nothing here to help the pelorus operators determine how to put the advice into practice.

EXAMPLE 4

Example 4 is the most complete and complex interaction concerning the strategies for sequencing the activities of the pelorus operators. Because of the size and complexity of this example, I will break it into segments punctuated with commentary. It begins with a question from the starboard pelorus operator (SW).

SW: I got two points. You want the fartherest first, and then the closest?

Recorder: Oh, OK.

SW: I got two points, right?

Recorder: Whatever is closer to the beam. Shoot the beam first. The one closer to sidewise. You got two points, um.

SW: So I shoot the fartherest one first, then the closest.

Recorder: If you got three, you shoot the one in the middle, then forward, then aft. If you got two, forward and aft.

SW: If you got . . . (interrupted by port wing pelorus operator)

Recorder: OK, just a reminder. You always shoot the beam bearings first. If you got three of them, you best shoot the ones . . . (port pelorus operator talking)

Recorder: If you got two of 'em, only shoot the ones up forward and back.

Plotter: Huh?

Recorder: I was just trying to explain which ones to shoot first. Beam bearings first.

Plotter: Beam, then forward and aft.

Recorder: Forward and aft. If he's got two, he's got to shoot forward first and then aft. (Recorder talks to port pelorus operator on headset.)

The origins of the starboard pelorus operator's ideas about shooting the most distant landmarks first is unknown. The instruction from the recorder, "If you got two, (shoot) forward and (then) aft," will lead to the wrong sequence if the aft bearing is closer to the beam than the forward one. The difficulty here is interpreting the meaning of the rule of thumb across a wide range of possible configurations of landmarks. After hearing this exchange, the plotter went out to the starboard wing to talk to the starboard pelorus operator. (In the conversation that followed, REFTRA refers to an upcoming inspection in which the crew's performance will be observed by an evaluation team.)

Plotter: Remember, one of the things you guys wanna do, the guys on the wings. Them REFTRA guys'll watch for it no matter who's out on the wings, and supposedly you're all inter ... any of you can be there. If the guy that sees ... When a round is comin' up and he knows, he says, see, you know, pretty clo ... you know about, you can tell. The guy who knows he's going to have a beam bearing. He gets through saying "OK on the next round I want you to have ..." and that guy can see he's gonna have it on the beam, tell the other guy "I've got the beam bearing." OK, so that ...

SW: Beam? Where is the beam? Right here?

Plotter: Right here (demonstrates with his arms). The beam is between here and here. The bearing that's chas ... changing fastest. Right along side of the ship. Even if it's out there, it's the bearing ...

SW: Uh huh

Plotter: ... that's changing the fastest. OK. That's your speed line. That's the one that should come first, and then the other guy can go ahead and shoot forward or, or, you know, he can go and shoot. But always the beam first. And if the guy that's got the beam bearing, see, the other guy can't see what you can see. Just like you can't see his. If you got the beam bearing, say "Hey, mine is the beam bearing." That way, he'll shut up ...

SW: You'll never have ...

Plotter: ... and let you give your beam.

SW: Comin' into a channel though, you could both have a bearing on the beam.

Plotter: True, you could, you could.

SW: You could, yeah, but not . . .

Plotter: But not very often, 'cause he don't give things that are right across from one another.

In this conversation it becomes evident that the pelorus operator was not at all clear on the meaning of "beam bearing." The plotter describes it to him, but also includes additional features of the beam bearings (e.g., "changing fastest" and "speed line") which are conceptually salient to the plotter but are probably meaningless to the pelorus operator, who is just trying to figure out how to identify the beam bearing. Notice also that the plotter links the observation of the bearing to the report of the bearing in his description of how the pelorus operators should negotiate the sequence of their activities. This is important because observation and report must be uncoupled in order to produce a more efficient procedure.

EXAMPLE 5

Later in the same entry, the ship was inbound. Course: 345°. Beam bearings: 075° and 255°. Landmarks: port, Point Loma 335; starboard, Dive Tower 045 and Hotel del 032. (See figure 4.8.) It is unclear what either participant takes "go first" to mean in the following exchange.

SW: When I got two points and he's only got one, shouldn't he let me go first?

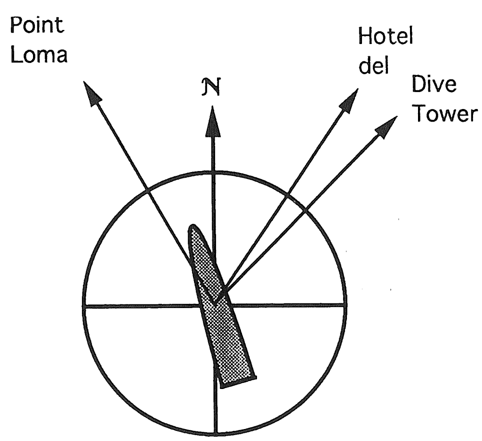

Figure 4.8 The situation of example 5.

Recorder: Nah, it doesn't matter really right now.

SW: Doesn't matter?

(S in conversation with CIC seems to have no time to pursue question from SW)

The answer to the starboard pelorus operator's question should have been an unequivocal "Yes." The recorder's response probably leaves the starboard pelorus operator in some confusion. Saying that it doesn't matter is a way for the recorder to indicate that he does not wish or does not have time to intervene in the negotiation between bearing takers at this moment. Unfortunately, this conversational move also has a substantive interpretation: that the number of landmarks one has is irrelevant to the order in which the bearings are reported. In this case, the starboard pelorus operator should observe Dive Tower first (before observing Hotel del, because Dive Tower is beamier) and should report first (that is, before the port pelorus operator reports, because the port pelorus operator has only one bearing to report). The two senses of "first" are different, as are the reasons for the two relative orderings. In either case, however, the starboard pelorus operator should have gone first.

EXAMPLE 6

Course: 35°. Beam bearings 083° and 263°. Landmarks: port, Point Loma 327; starboard, Dive Tower 058, Hotel del 044. (See figure 4.9.) In this sequence the recorder encourages the linkage of shooting and reporting.

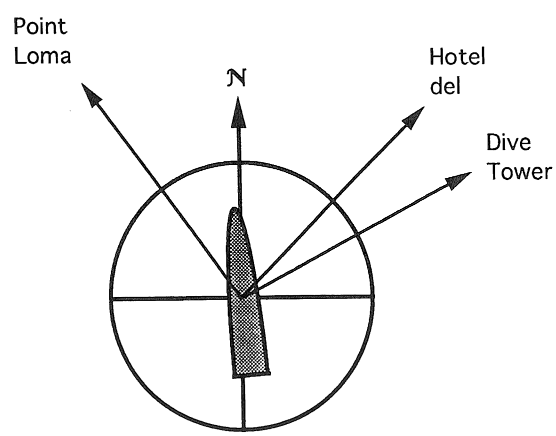

Figure 4.9 The situation of example 6.

SW: John?

Recorder: Yo!

SW: Is the Dive Tower right on our beam?

Recorder: Say again?

SW: Dive Tower. Isn't it just about on our beam?

Recorder: Yeah, just about. (2 seconds) OK, Shades?

PW: What?

Recorder: Steve's gonna be shooting the Dive Tower first, so let him say, uh, let him say the bearing first.

PW: You want Point Loma last, then?

Recorder: Yeah, that's fine.

In this example, the starboard pelorus operator's question about the beam status of the Dive Tower is interpreted by the recorder as also being an indirect request to shoot and report that bearing first, perhaps in accordance with their previous discussion. The recorder takes up the role of negotiating the sequence and seems to expect the port pelorus operator to share this interpretation of the starboard pelorus operator's request. Once again, the recorder's instructions explicitly combine shooting with reporting.

EXAMPLE 7
Time: 6 minutes later. Course 353°. Beam bearings: 083° and 263°. Landmarks: port, Point Loma 275°; starboard, Hotel del 066°, Light Zulu 049°. (See figure 4.10.)

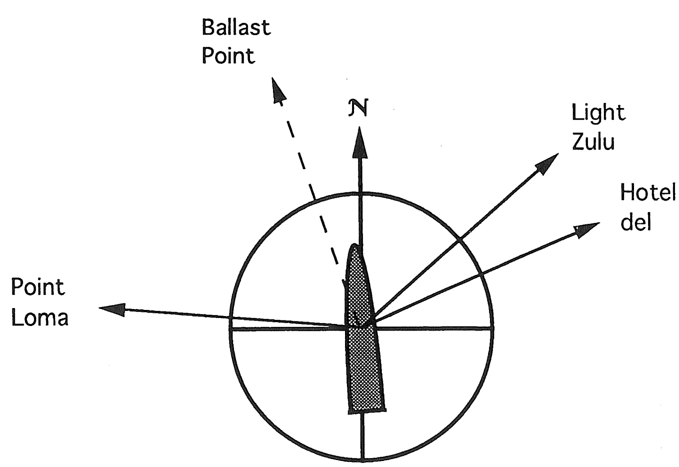

Figure 4.10 The situation of example 7.

Plotter: What did you take a bunch of beam bearings for? Why ain't you shooting up there (ahead) some place. Look what you did. You shot three beam bearings. You shot three beam bearings. You better tell 'em to shoot from up ahead some place.

Recorder: OK. Drop Point Loma and pick up Ballast Point, John.

PW: OK.

Failure to Uncouple Shoot and Report Actions

The rule "shoot the beam bearing first" works fine in solo watchstanding. Yet the attempts of the navigation team to use that rule to coordinate their actions through time fail repeatedly. Why is the application of this simple rule so difficult? Why is the team unable to use this rule to organize its performance? The above examples of instructions concerning the taking of beam bearings provide some clues.

When the rule is invoked in Standard Steaming Watch by a single quartermaster standing watch alone, the beam bearing refers to the bearing in the set of three that is nearest the beam of the ship, and the sequence specifier "first" is established with respect to the entire set of three bearings. In the group version of the task, a pelorus operator cannot always determine whether any bearing he has been assigned is nearer the beam than any bearing assigned to the other pelorus operator. A pelorus operator stationed on one wing of the ship cannot give either of these words the meaning it has for a solo watchstander. It is as though other words were missing from the simple statement of the rule. A more explicit version of the rule in the solo watchstanding case would be "*Of the set of three bearings*, shoot the beam bearing first." It is not necessary to say these words in the solo watchstanding context, because the entire set of three bearings is the watchstander's responsibility. Their presence in that context is not needed, and their absence when the context has changed is not noticed. If these words had been present, the problems of giving the rule to the individual members of the team may have been more apparent. The statement of the rule implies or assumes a perspective that takes in all three bearings at once. That is the meaning of 'beamiest' that we get from looking at the diagrams, it is the meaning exchanged by the recorder and the plotter when they are looking at the chart, and it is the meaning that the plotter brings out onto the wing when he explains to the pelorus operator how to apply the rule. But the perspective on which this meaning rests is not available to the pelorus operators. Neither pelorus operator can see the entire set, and neither can really know the relation of the bearings on his side to those on the other. The pelorus operators need a meaning of 'beamiest' that they can apply on the basis of what they can see, and they cannot see all three bearings at once. Transporting knowledge from the solo performance context to the group performance context is very problematic. It may require changes in the meanings of words.

There is also considerable difficulty in interpreting the meaning of the rule across a wide range of possible configurations of bearings. The pelorus operators have never stood watch alone, and may not even know what the beam is. This highlights the fact that the group performance requires a particular distribution of knowledge.

Both the plotter and the recorder link the observation of the bearing to the act of reporting the bearing in their descriptions of how the pelorus operators should negotiate the sequence of their actions. This has multiple causes. First, observing and recording are a unit in the solo version of the task (which is the source of the rule). Second, an explicit vocabulary is required to sort out observing from reporting. It is not easy, in the absence of a diagram, to describe what the order of actions should be. It is still more difficult to negotiate this sequence without a prior agreement about how observing can be decoupled from reporting. What is needed is a language for the two aspects of the rule: The operator who has two bearings should report before the operator who has only one, and he who has two bearings should always shoot the beamier of the bearings before the other. The rule that comes from solo performance has no such terms.

Here is an aspect of the organization of team activity that is problematic for the team. The members perceive it as being a problem, and they apply themselves to it, but they come to no satisfactory solution. Transporting the simple rule of thumb from the solo watchstanding configuration to the group configuration presents unexpected difficulties. The words of the rule themselves seem to change meanings when the rule is moved to a new context, and new words seem necessary to make distinctions in the new context that were not needed and not made in the old context. The conceptual linkage between observing and reporting prevents the team from exploiting possibilities of the socially distributed system for

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manipulating the temporal relations among actions. It is difficult to reason about a system as complex as this from a position within it. Quartermasters are not trained in the sorts of reflection on organization that are required to solve problems like this.

Going Beyond the Job Description

One important aspect of the social distribution of this task is that the knowledge required to carry out the coordinating actions is not discretely contained inside the various individuals. Rather, much of the knowledge is intersubjectively shared among the members of the navigation team. This permits the human component of the system to act as a malleable and adaptable coordinating tissue, the job of which is to see to it that the proper coordinating activities are carried out. In their communication and in their joint actions, the members of the navigation team superimpose themselves on the network of material computational media. They provide the connecting tissue that moves representational state across the tools of the trade. In addition, they dynamically reconfigure their activities in response to changes in the task demands. This amounts to a restructuring of functional systems that transcends the individual team members. The individual team members do their jobs by constructing local functional systems that bring media in their immediate environment into coordination. They also must coordinate their activities of helping one another achieve coordination. The computation is implemented in the coordination of representational states, and the human participants coordinate their coordinating actions with one another.

Shared Task Performances

Sometimes the coordination of actions occurs at a very fine grain. One day during Standard Steaming Watch, Silver and Smith were working the chart table together. They needed to use the hoey determine the direction of a line between two points. Smith placed the tip of his pen on the one of points. Silver put the point of his pencil down on the second point and pushed the edge of the hoey arm up against the pencil and pen points. Then, while Silver held the hoey arm in place, Smith rotated the base of the protractor to align it with a latitude line and read the bearing from the hoey scale. This *ad hoc* division of labor was based on a shared understanding of the microstructure of the task. There was no verbal negotiation of the parts of the task to be done by each man; they simply created this coordination in the doing of the task. The social skills required to enter into shared task-performance relationships probably develop fairly early in life.

Distributed Memory

Task-relevant information is present in many representations in this system. Some of these representations are in the minds of the participants. During an exit from a harbor, the plotter expected a 1000-yard interval between fixes. Instead he measured only 700 yards. This indicated that the ship had slowed from 10 to about 7 knots. This is troubling, because it indicates a discrepancy between the information used to project the dead-reckoned position and the actual observations. To resolve the discrepancy, the plotter began by talking to himself, but quickly addressed a question to the keeper of the deck log.

Plotter: This is not showing no, a no goddamn ... they show a two-thirds, still got a two-thirds bell, right?

Deck log: One-third bell.

Plotter: Why?

CIC talker: Got the pilot off.

Plotter: Oh, that's why. OK, he's [the pilot] getting off right now, isn't he?

CIC talker: Yeah. He [the OOD] went back to 5 knots.

Plotter: That's what messed me up. They have this goddamn 7-knot goddamn thing in here and I'm trying to figure out why.

In this exchange, both the CIC talker and the keeper of the deck log provide the plotter with task-relevant representational state. The plotter could have gotten the information about the one-third bell (ahead one-third on the engine-order telegraph) from the deck log itself, or from the engine-order telegraph, or from the leehelmsman as well as from the keeper of the deck log. This bit of system state is redundantly represented in the memories of several participants, and in written records. The information about the departure of the harbor pilot was probably not present in any record at this time, because as far as the bridge crew knew the pilot was still on board.

Still, the CIC talker knew about this and was able to judge that it would be of use to the plotter at this time.

In another instance, while simultaneously watching a fishing boat that crossed close under the bow of the ship and discussing the watch bill for the remainder of the day, the plotter and recorder missed a fix time. This problem was caught by the keeper of the deck log about 2 minutes late.

Deck log: Chief, you're going to have another call. Missed at 3. Your round at 3.

Plotter: I'll get one here in a minute.

Recorder: Stand by to mark.

Plotter: Time is 5, yeah 5; we'll just kind of space this one out.

Even though timing the fixes is not part of the keeper of the deck log's job, he is a participant at the chart table and in this case, happens to have noticed that a scheduled fix was missed. This sort of overlapping knowledge distribution is characteristic of cooperative work and is an important source of the robustness of such systems in the face of error and interruption.

Recorder Cuing the Plotter

With only two landmarks visible, the team substituted a radar range on one of the visible landmarks for the third line of position. After advising the pelorus operators to stand by for a round, the recorder turned to the plotter and said: "Get a range, Chief? (2 seconds) Mark it." The plotter had apparently forgotten that he was required to take the radar range of the landmark as part of the position fixing operation. In this case, an element of the sequential organization of the plotter's activity was provided by the recorder. This is not strictly in accordance with the normal division of labor. The plotter was supposed to remember that the "stand by to mark" signal was his cue to take the radar range. He and the recorder had come to an agreement about a nonstandard division of labor to meet the needs of an unusual situation. We may speculate that the recorder's memory for the plotter's role was in part cued by the fact that he had labeled a column in the bearing record log as "Range Pt. Loma." The need to fill the cell in the bearing log at the intersection of this labeled column with the row representing the current time acts as a memory for the decision to take the radar range and may remind the recorder of the plan for getting the range.

Landmark Descriptions

Since the ideal manning requirements are seldom met, it is often the case that the pelorus operators are not entirely familiar with the landmarks they will be required to observe. When pelorus operators fail to locate a landmark, the plotter and recorder may attempt to help them out by providing verbal descriptions. In the following example, the port pelorus operator is unable to find a landmark. (This one, the Dive Tower, is frequently a problem.) Notice also that the plotter interjects additional sequencing advice at the beginning of the fix cycle. (The starboard pelorus operator's name is Mark). Those portions of the recorder's talk that are transmitted over the phone circuit appear in boldface.

Recorder: Stand by to mark, Point Loma, Hotel del, and Dive Tower.

Plotter: Tell him to take Point Loma first. It's on his beam.

Recorder: Take Point Loma first, Mark. Beam bearing first. Mark it.

SW: Point Loma, 3 5 9.

Recorder: 3 5 9 Point Loma.

Nav: Ten knots good speed?

Plotter: Yes. Anything you want. We're clear now. Wherever you want to go.

PW: Hotel del 0 3 8.

Recorder: 0 3 8 Hotel del.

PW: I can't find the Dive Tower.

Recorder: Can't find the Dive Tower.

Plotter: Tell him it is about 8 degrees, 9 degrees to the right of Hotel del (plotting)

Recorder: Nine degrees?

Plotter: Yeah.

Recorder: It's about 9 degrees to the right of Hotel del. It's about 0 4 6.

The clue provided by the plotter in this case is not a description of the landmark, but a location relative to a previously reported landmark toward which the pelorus operator should look. This is evidence of how strong the expectations of the position of the landmark are. Also notice that the recorder transforms the description even further, converting it by mental arithmetic to a bearing at which the pelorus operator should look for the landmark.

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In this example we see something of the relationship of social structure and computational structure. Given a computational procedure and a social organization, there are better and worse ways to distribute the computation across the social network. One way in which the distribution of tasks can be better or worse concerns the relation between the amount of information that must be passed between computational segments and the capacity of the medium of communication between the participants responsible for those segments. That is a computational argument for a particular decomposition of the task. The observed decomposition works well in many respects but is frustrating for certain classes of problems.

Recorder Setting Up Plotting Tool for Plotter

In another instance, the plotter was called away from the chart table just as the bearings of the landmarks were reported. After recording the bearings in the bearing record log, the recorder reached across the chart and set the hoey arm to the value of the first bearing. When the plotter returned to the chart table, he looked in the log for the bearing. When he looked at the hoey, he noticed that it had already been set to the proper bearing. He then simply aligned it with the chart and plotted the line of position. Setting the hoey was not in the recorder's job description, but it was a way of pushing the representational state a little further toward its end point.

Flexibility and Robustness

These examples also illustrate the robustness of the system of distributed knowledge. If one human component fails for lack of knowledge, the whole system does not grind to a halt. If the task becomes difficult or communications break down, the navigation team does not have the option of stopping work. The task is driven by events and must be performed as long as the ship is underway. In response to a breakdown, the system adapts by changing the nominal division of labor. It is the bearing taker's job to find the landmarks, for example, but if he is unable to do so, some other member of the team will contribute whatever is required to ensure that the landmarks are found and their bearings observed. This robustness is made possible by the redundant distribution of knowledge among the members of the team, the access of members to one another's activities, and the fact that the individual workloads are light enough to permit mutual monitoring and occasional assistance. Both the knowledge required to do the task and the responsibility for keeping the system working are distributed across the members of the navigation team. We can think of the team as a sort of flexible organic tissue that keeps the information moving across the tools of the task. When one part of this tissue is unable to move the required information, another part is recruited to do it.

Performance as a Language of Social Interaction

The division of labor mandated in Sea and Anchor Detail distributes the elements of the fix cycle across social space. Wherever computations are distributed across social organization, computational dependencies are also social dependencies. Performance is embedded in real human relationships. Every action is not only a piece of the computation, a bit of the task completed; it is also a social message. Building and maintaining good social relationships becomes an important motive for competent performance. In order to do the computation, the members of the team must interact. They depend on one another. More precisely, the portion of the computation for which each is responsible may depend on the portions for which the others are responsible. In order to plot the next line of position, the plotter needs the bearing, which means he needs to communicate with and secure the cooperation of the pelorus operator.

An important aspect of these interrelated social and computational structures is that both of them provide constraints on the behavior of the participants. One can embed a novice who has social skills but lacks computational skills in such a network and get useful behavior out of that novice and the system. The reason is that the social structure (and the structure of the tools) of the task may provide enough constraints to determine what turns out to be a well-organized computational behavior even though the behavior was not motivated by any understanding of the computation. The task world is constructed in such a way that the socially and conversationally appropriate thing to do given the tools at hand is also the computationally correct thing to do. That is, one can be functioning well before one knows what one is doing, and one can discover what one is doing in the course of doing it.

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The social structure is not only the framework on which the communication is based, it is also the mechanism that is in place prior to the interactions to ensure that they take place as required. Why should the pelorus operator cooperate? Because adequate performance is the currency of social interaction. The novice quartermaster is institutionally located in such a way that his actions can be taken both as contributions to the process and as claims to or justifications of membership in the social world of the other quartermasters. And, since this is the military, a novice who does not perform adequately can be harshly sanctioned.

How to Say Things with Actions

My initial assumption about work in military settings was that behaviors are explicitly described and that people act more or less as automatons. It should be apparent by now that this is far from the case. I also naively assumed that most communication on the job would be part of the job and nothing more. As I worked with the data, something that Roy D'Andrade once said kept coming back to me. A student was making a point about what people do at work, saying that in an auto factory people mostly make cars. Roy said something like: "How do you know what they are doing? Maybe what they are making is social relationships and the cars are a side effect."

It is clear that when quartermasters report bearings, assign landmarks, or ask for data, they are not just constructing position fixes; they are also constructing social relationships. And the fact that their respective responsibilities are so well specified does not eliminate the possibility of loading social messages into the communication acts that make up the work. In fact, the well-formed expectations about what constitutes competent verbal behavior in this setting may give the participants an especially subtle means of communicating social messages. Doing the absolute bare minimum required when others know that one has the time and resources to do more is a clear statement.

Computational Properties of the Navigation Team

Local functional systems are established in the individual jobs. Each member of the navigation team is responsible for the construction of a number of local functional systems. These are the processes of bringing media into coordination as described in chapter 3.

These local functional systems are coordinated in the interaction of the members of the team. In their interactions, the team members assemble the component functional systems into a larger functional system.

The larger system has cognitive properties very different from those of any individual. In fact the cognitive properties of the navigation team are at least twice removed from the cognitive properties of the individual members of the team. The first remove is a result of the transforming effects of the interactions with the tools of the trade (chapter 3); the second remove is a consequence of the social organization of distributed cognition.

In Sea and Anchor Detail the navigation team implements a distributed problem-solving system in which various elements of the computation are embodied in the operations of functional systems constructed by the members of the team. Among the advantages of distributed processing discussed by Chandresekaran (1981) are the following:

The decomposition of processing is a strategy for controlling the complexity of computation. By breaking the problem down into pieces, the team can have several workers operating in parallel. This decomposition of the task also permits each member of the team to attend closely to only a limited set of data. As Chandresekaran points out, the complexity of computation is often an exponential function of the size of the input space. If the problem can be divided up, each person can deal with a tractable problem. For example, each pelorus operator needs to deal with the landmarks on only one side of the ship's track. It is possible to learn the landmarks for the starboard side without knowing the landmarks for the port side. There are also filtering processes applied that prevent the growth of input space. Thus, the recorder does not normally have to deal with the complexity of the visual scene outside the ship. His experience of the bearings is pre-processed by the pelorus operators and takes the form of strings of spoken digits. An important advantage of social distribution of computing is that novices can be embedded in social arrangements such that much of the structure required for them to organize their activity is available in the social relations. Even though the skills have mainly social

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A second property noted by Chandresekaran is that distributed computing "increases the prospects for graceful degradation" of system performance when components fail. This is apparent in the response of the navigation team to local failures such as the inability of a pelorus operator to locate a landmark. Because the members of the team have overlapping knowledge, it is possible for them to reconfigure dynamically in response to a problem. The individuals are a sort of flexible tissue that moves to ensure the propagation of task-relevant representational state. Because their competences overlap and they have access to one another's activities, they are able to aid one another and fill in for one another in the event of a local failure.

Adaptation to change may be easier in distributed than in centralized systems. Chandresekaran says that "as the external environment changes, distributed information processing makes adaptation to change easier, since again, as long as the rate of change is not large, changes to the system can be mostly local." I will discuss an example that illustrates this in some detail in chapter 8.

Having the pelorus operators negotiate the shooting sequence among themselves is an example of the uses of modularity. Notice that this modularity was violated when the starboard pelorus operator asked the bearing recorder to settle the shooting and reporting order.

One of the costs of distribution is the filtering performed by the sensors. The pelorus operators are expected to pass only the results of their computations to the bearing recorder. All information about the process that went into achieving that result is lost in the report of the bearing as a single number. This reduces the bandwidth required for communication (the phone circuit is adequate for this), and it also reduces the processing demands on the central processor (plotter). However, this kind of filtering makes it more difficult to diagnose the causes of errors committed by the pelorus operators, since nothing of the process is normally communicated.

Representing the bearings symbolically also introduces new possibilities for error. For example, the landmarks light 2 and light zulu are very different from each other in location and appearance. It is unlikely that one would ever be mistaken for the other. Their symbolic representations, "light 2" and "light Z," however, are very similar and might easily be confused. This potential was recognized by the plotter, and he instructed the recorder to put a slash through the Z.

Another potential cost of distribution is the potential disruption of one processor by another. The buffers are a way to overcome this sort of temporal discoordination. The phone circuit has different properties from the bearing log because one endures in time while the other does not.

The problem of the design of the distribution of labor remains. As we saw with the case of beam bearings, the mapping from individual performance to the group configuration is a nontrivial one. Opportunities exist in the distributed version of the task that are simply not present in the solo-performance case. Finding and exploiting these opportunities may require reflection on explicit representations of the work itself, and the members of the navigation team are ill equipped to do such reflection.

The theme of this chapter is that organized groups may have cognitive properties that differ from those of the individuals who constitute the group. These differences arise from both the effects of interactions with technology and the effects of a social distribution of cognitive labor. The system formed by the navigation team can be thought of as a computational machine in which social organization is computational architecture. The members of the team are able to compensate for local breakdowns by going beyond the normative procedures to make sure that representational states propagate when and where they should. The difficulty in mapping a rule of thumb developed for solo watchstanding into the group configuration highlights the differences between these modes of operation and provides insights into the limits on the team's abilities to explicitly plan the coordination of their actions.